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RESEARCH MEMORANDUM

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BLOW-OUT VELOCITIES OF SOLUTIONS OF HYDROCARBONS AND BORON HYDRIDE - HYDROCARBON REACTION PRODUCTS IN A $1\frac{7}{8}$-INCH-DIAMETER COMBUSTOR

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RESEARCH MEMORANDUM

BLOW-OUT VELOCITIES OF SOLUTIONS OF HYDROCARBONS AND BORON HYDRIDE - HYDROCARBON REACTION PRODUCTS IN A $1\frac{7}{8}$-INCH-DIAMETER COMBUSTOR

By James F. Morris and Albert M. Lord

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SUMMARY

Combustion blow-out velocities were determined in a $1\frac{7}{8}$-inch-diameter combustor for solutions of reaction products of ethylene and decaborane, acetylene and diborane, and methylacetylene and diborane in JP-4; and the data are compared with previously reported values for pentaborane - JP-4 solutions. For a given equivalence ratio and boron hydride reaction product concentration, blow-out velocities decrease in the following order: (1) the ethylene - decaborane reaction product (below equivalence ratio of 1.35), (2) pentaborane, (3) the acetylene - diborane reaction product, and (4) the methylacetylene - diborane reaction product. The blow-out velocities for a given boron hydride reaction product JP-4 solution at constant equivalence ratio diminish with decreasing concentration to that of JP-4. It appears that the tendency to deposit degraded products at operating conditions specific to this apparatus increases in the following order: (1) ethylene - decaborane, (2) acetylene-diborane, and (3) methylacetylene - diborane reaction products.

INTRODUCTION

Boron hydride compounds have been a subject of concentration at the NACA Lewis laboratory because they exhibit potentialities as fuels in aircraft jet-propulsion systems. Analytical and experimental investigations have shown these fuels to possess high combustion efficiencies, high air and fuel specific impulses, and wide combustion limits (refs. 1 to 3). Problems arise in the practical use of these fuels, however, due to their low auto-ignition temperatures, toxicity, and high vapor pressures. In order to obtain fuels having better safety and handling characteristics, consideration has therefore been given to blends of boron hydrides and hydrocarbons and reaction products of boron hydrides and hydrocarbons.

The object of this investigation was to evaluate the combustion behavior of blends of JP-4 and three new fuels obtained by reacting boron hydrides with unsaturated hydrocarbons. These reaction products were made available by the Bureau of Aeronautics, Department of the Navy, as part of Project ZIP.

Blow-out velocities have been shown to correlate with laminar flame speeds of fuels (ref. 1), and laminar flame speeds yield effective combustor-performance indices (refs. 4 to 6). Therefore, blow-out velocities were the criteria utilized to reveal the combustion behavior of the fuels. Blow-out velocities in a $1\frac{7}{8}$-inch-inside-diameter combustor 3369 were determined for solutions of: 10- and 20-percent (by weight) of a reaction product of acetylene and diborane in MIL-F-5624A grade JP-4; 5.5-, 15.7-, and 30.7-percent of a methyl acetylene - diborane reaction product in JP-4; and 10 percent of an ethylene - decaborane reaction product in JP-4. The data are compared with similar data reported in reference 1 for various pure fuels and blends of pentaborane in JP-4 fuel.

APPARATUS AND PROCEDURE

Installation

The combustor and the fuel system are shown schematically in figure 1. The flow of air entering the burner was regulated with a throttling valve and measured with a rotameter. The fuel system used for the boron hydride reaction products in JP-4 solutions incorporated all metal parts except for seals made of Teflon because of the corrosiveness, spontaneous inflammability, and toxic properties of boron hydride compounds. The combustor details are shown in figure 2. Fuels were atomized with metered air and additional metered combustion air was injected through the porous walls of the mixture preparation zone. The mixing chamber opened directly into a cylindrical chamber which was $1\frac{7}{8}$-inch inside diameter and 8 inches long. The sudden expansion from the mixing chamber to the combustion chamber acted as a flame holder.

An acetylene-air torch ignited the fuel-air mixture in the combustion chamber through a 1/4-inch hole located in the upstream end of the combustion chamber. The torch was mechanically linked so that the hole could be closed after ignition.

The combustor exhausted to the atmosphere; the exhaust was then induced into a 6-inch-diameter exhaust system containing extensive water sprays for exhaust-product treatment.

Considerable variations in blow-out velocities for a given fuel observed in reference 1 were attributed to the air-atomizing fuel nozzle used in the previous investigation. Therefore, changes to effect operational stability were made in the fuel nozzle before the initiation of this investigation. While the principles of operation and primary

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dimensions remained the same in the new nozzle design, definite differences in blow-out velocity curves for JP-4 and propylene oxide were observed. The new blow-out velocities for JP-4 ranged from approximately 80 to 110 percent of the previously reported values (ref. 1) as equivalence ratios were varied from 0.6 to 3.0.

Test Procedure

For the determination of the blow-out limits, the atomizing-air flow was held constant, a steady fuel flow was maintained, and the combustion-air flow was set low enough for ignition of the fuel-air mixture and was gradually increased until flame failure occurred.

The velocity at blow-out was computed from the air flow at a reference area corresponding to the combustion-chamber inlet $\left(1\frac{7}{8}\text{-in. diameter}\right)$ with atmospheric pressure and temperature assumed.

The air temperature varied from 60° to 90° F, and the humidity was not controlled although a water separator removed water droplets in the inlet-air line. Reference 5 reported that humidity can make a change of as much as 6 percent in the burning velocity of propane.

Fuels

The following fuels were used in this investigation:

Fuel designation	[1]Acetylene - diborane reaction product concentration, weight percent	[1]Methylacetylene - diborane reaction product concentration, weight percent	[1]Ethylene - decaborane reaction product concentration, weight percent	MIL-F-5624A grade JP-4 concentration, weight percent	Remarks
JP-4	--	----	--	100.0	MIL-F-5624A
Propylene oxide	--	----	--	-----	Commercial grade
NACA 54-120	10	----	--	90.0	-----------
NACA 54-121	20	----	--	80.0	-----------
NACA 54-117	--	5.5	--	94.5	-----------
NACA 54-118	--	15.7	--	84.3	-----------
NACA 54-119	--	30.7	--	69.3	-----------
NACA 54-122	--	----	10	90.0	-----------

[1]Reaction products of unsaturated hydrocarbon compounds and boron hydrides (not pure compounds) supplied by Mathieson Chemical Corp., Ballston Spa, N. Y.

RESULTS AND DISCUSSION

Figure 3 demonstrates the variation of blow-out velocity with equivalence ratio for JP-4 fuel and solutions of the acetylene - diborane reaction product in JP-4. Within the equivalence ratio range 0.6 to 1.6, blow-out velocities increase regularly with acetylene - diborane reaction product addition to JP-4 at any given equivalence ratio. Above an equivalence ratio of 1.6 the curve for 10-percent acetylene - diborane reaction product approximately parallels that for JP-4. The curve for 20-percent acetylene - diborane reaction product continues to increase with slopes greater than those for the 10-percent solution.

Figure 4 shows blow-out velocities for the methylacetylene - diborane reaction product solutions in JP-4. In this instance the lower concentrations (15.7 and 5.5 percent) yield comparatively small increases in blow-out velocities over those of JP-4. However, 30.7-percent methylacetylene - diborane reaction product produces significant elevation of the blow-out velocities relative to those of JP-4.

Figure 5 illustrates the blow-out velocity variation with equivalence ratio for a 10-percent ethylene - decaborane reaction product solution in JP-4. Since a very limited quantity of the solution was available, the resulting data reveal only a small portion of the blow-out velocity - equivalence ratio concentration relation. However, for a given equivalence ratio in the range from 0.6 to 1.3, a 10-percent addition of the ethylene - decaborane reaction product produced a blow-out velocity at least 50 percent greater than that of JP-4.

Figure 6 presents a comparison of blow-out velocities of boron-hydride compound solutions and the more common fuels, JP-4 and propylene oxide. Also included in figure 6 are blow-out velocities for blends of pentaborane and JP-4 fuel. The values for the pentaborane blends are those from reference 1 corrected to allow for changes in blow-out velocity level made subsequent to the investigation reported in reference 1. These changes resulted in slightly modified operational curves for JP-4 and propylene oxide. The corrections were made by the following proportional relation

$$\left(\frac{V_B - V_{JP\text{-}4}}{V_{PO} - V_{JP\text{-}4}} = \frac{U_B - U_{JP\text{-}4}}{U_{PO} - U_{JP\text{-}4}}\right)_{\text{fixed equivalence ratio}}$$

where

V blow-out velocity of reference 1

U blow-out velocity of this investigation

PO propylene oxide

JP-4 JP-4 (MIL-F-5624)

B pentaborane blend

At equivalence ratios below unity, the blow-out velocities of some of the fuels in figure 6 decrease in the following order: (1) 10-percent ethylene - decaborane reaction product, (2) 20-percent pentaborane,
3369 (3) 20-percent acetylene - diborane reaction product, and (4) 30.7-percent methylacetylene - diborane reaction product. The blow-out velocity of a JP-4 solution containing 10 percent of the ethylene - decaborane reaction product approaches that of a 10-percent pentaborane solution at an equivalence ratio of 1.35. The blends of boron hydride - unsaturated hydrocarbon reaction products that were investigated showed blow-out velocities intermediate between those for JP-4 fuel and propylene oxide.

Figure 7 shows a cross plot of the data of figure 6; blow-out velocities at an equivalence ratio of unity are shown for various concentrations of the boron hydride reaction products. The values for pentaborane are transposed as previously described. Blow-out velocities for propylene oxide, neohexane, and JP-4 have been included as an additional reference scale. Figure 7 summarizes and emphasizes the previous discussions on relative reactivities of boron hydride compound solutions in JP-4.

Figures 8, 9, and 10 are photographs showing front views of $1\frac{7}{8}$-inch-diameter combustor after high-equivalence-ratio runs of JP-4 solutions of 30.7-percent methylacetylene - diborane reaction product, 20-percent acetylene - diborane reaction product, and 10-percent ethylene - decaborane reaction product, respectively. They illustrate an apparent competition under the conditions of operation between combustion and thermal degradation mechanisms. The extent of deposition decreases in the above order for the specific conditions utilized in this work. The combustor deposit of the 20-percent pentaborane solution in JP-4 observed in reference 1 was comparable to that of ethylene-decaborane. Reaction products, types, reaction rates, and equilibria are dependent at least on "dwell" time, concentration, temperature, and pressure effects. Therefore, no generalizations relative to degradation of boron hydride - unsaturated hydrocarbon reaction products should be formulated on the limited basis of this investigation.

Blow-out velocities below 22 feet per second were not reproducible in check tests. At least two conditions contributed to this malfunction: (1) insufficient air flow across the porous chamber wall to prevent acculation of liquid and degraded products on mixing chamber walls, and (2) a major fraction of total-pressure drop at low fuel flows occurring at the throttle valve in the fuel system rather than at the injector.

The helium used to pressurize the fuels dissolved in the liquid fuels at the relatively high pressures used. Then the helium was released from solution at the point of controlling pressure drop. When the helium was released at the throttle valve, liquid flowed intermittently in remaining fuel lines. At this condition discontinuity in burning due to fuel interruptions could not be distinguished from true blow-out.

Further restrictions must be imposed on interpretation of the data reported herein in view of the inlet conditions in the $1\frac{7}{8}$-inch-diameter
combustor. These represent only a small portion of the spectrum of con- 3369
ditions which could be encountered by these fuels in ram-jet, turbojet, and turbojet afterburner applications. The physical and chemical reactions which predominated could vary widely from those prevailing in typical aircraft combustors.

SUMMARY OF RESULTS

Blow-out velocities of blends of boron hydride - unsaturated hydrocarbon reaction products in JP-4 were determined in a $1\frac{7}{8}$-inch-inside-diameter combustor. From these investigations and previous work with pentaborane - JP-4 blends, the following results were obtained:

1. For given equivalence ratio and boron - hydride reaction product concentration in JP-4 solutions, blow-out velocities decrease in the following order: (1) ethylene - decaborane reaction product (below an equivalence ratio of 1.35), (2) pentaborane, (3) acetylene - diborane reaction product, and (4) methylacetylene - diborane reaction product.

2. For a given equivalence ratio, blow-out velocities of JP-4 solutions of the compounds diminish with decreasing boron hydride concentration.

3. The tendency to deposit degraded products or to yield partial combustion under the limited conditions of this investigation increases in the following order: (1) ethylene - decaborane reaction product, (2) acetylene - diborane reaction product, and (3) methylacetylene - diborane reaction product.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, June 21, 1954

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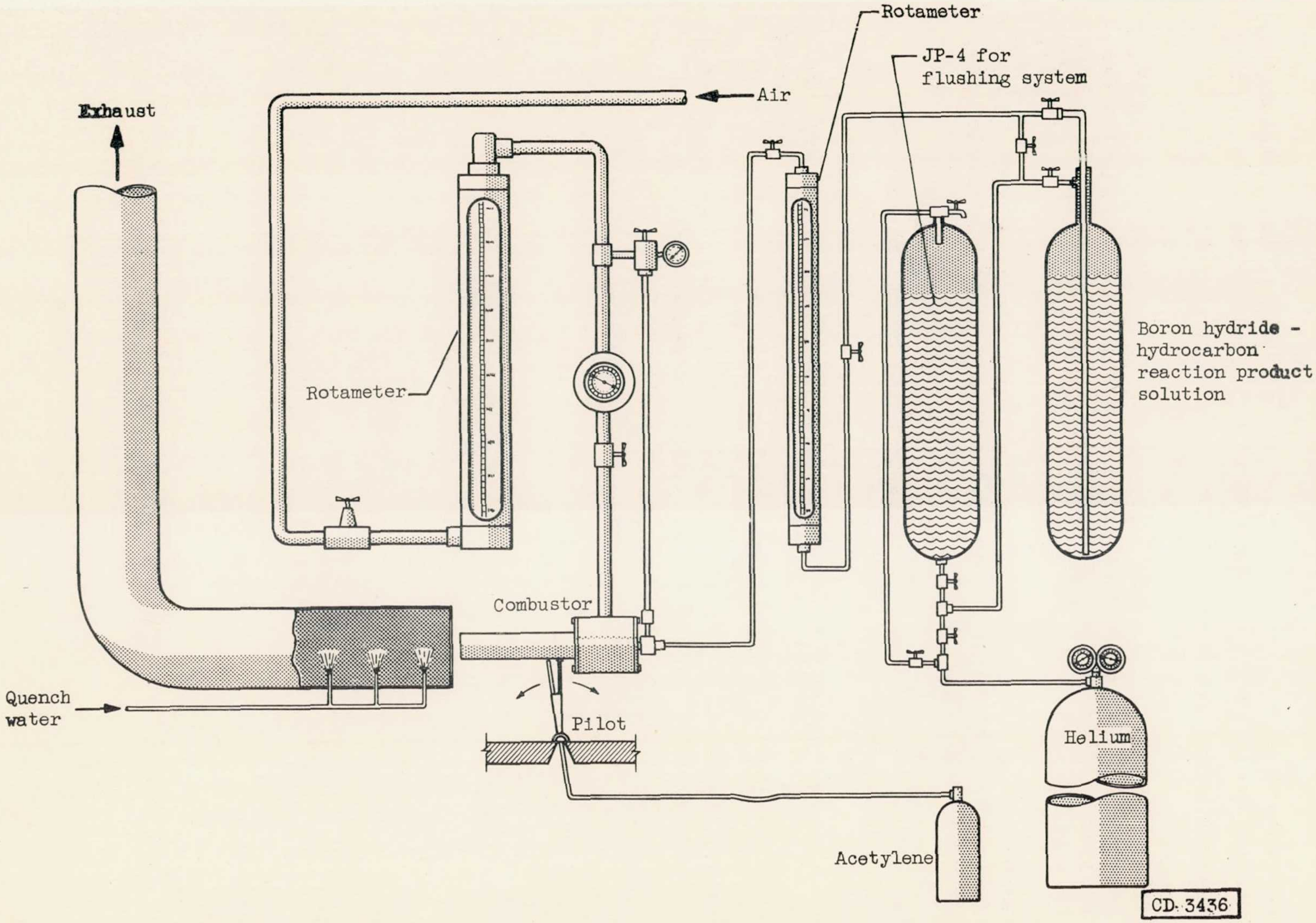

Figure 1. - Combustor with fuel system for boron hydride - hydrocarbon reaction product solutions.

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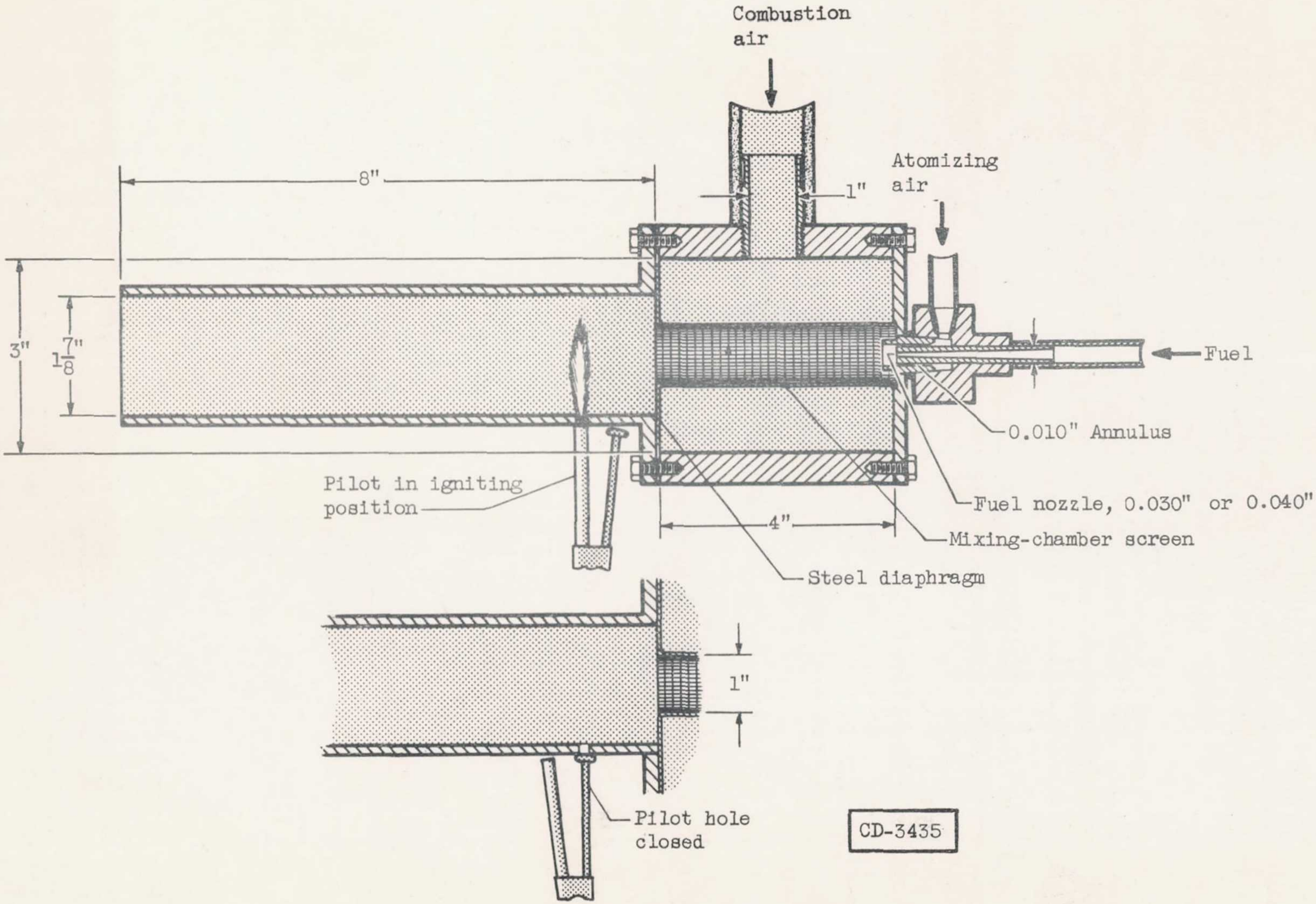

Figure 2. - Combustor, pilot, and mixing chamber.

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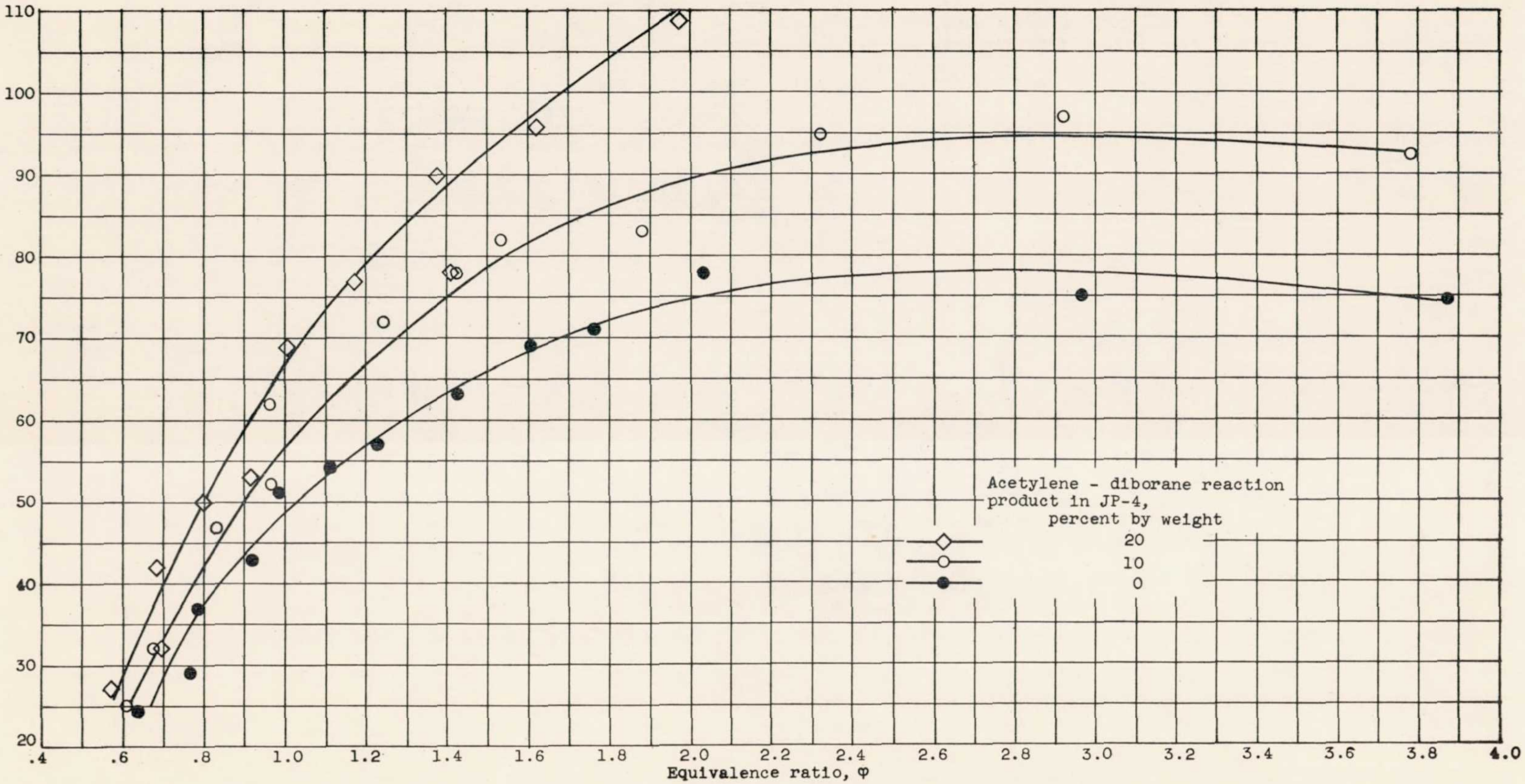

Figure 3. - Blow-out velocities of an acetylene - diborane reaction product in JP-4 solutions.

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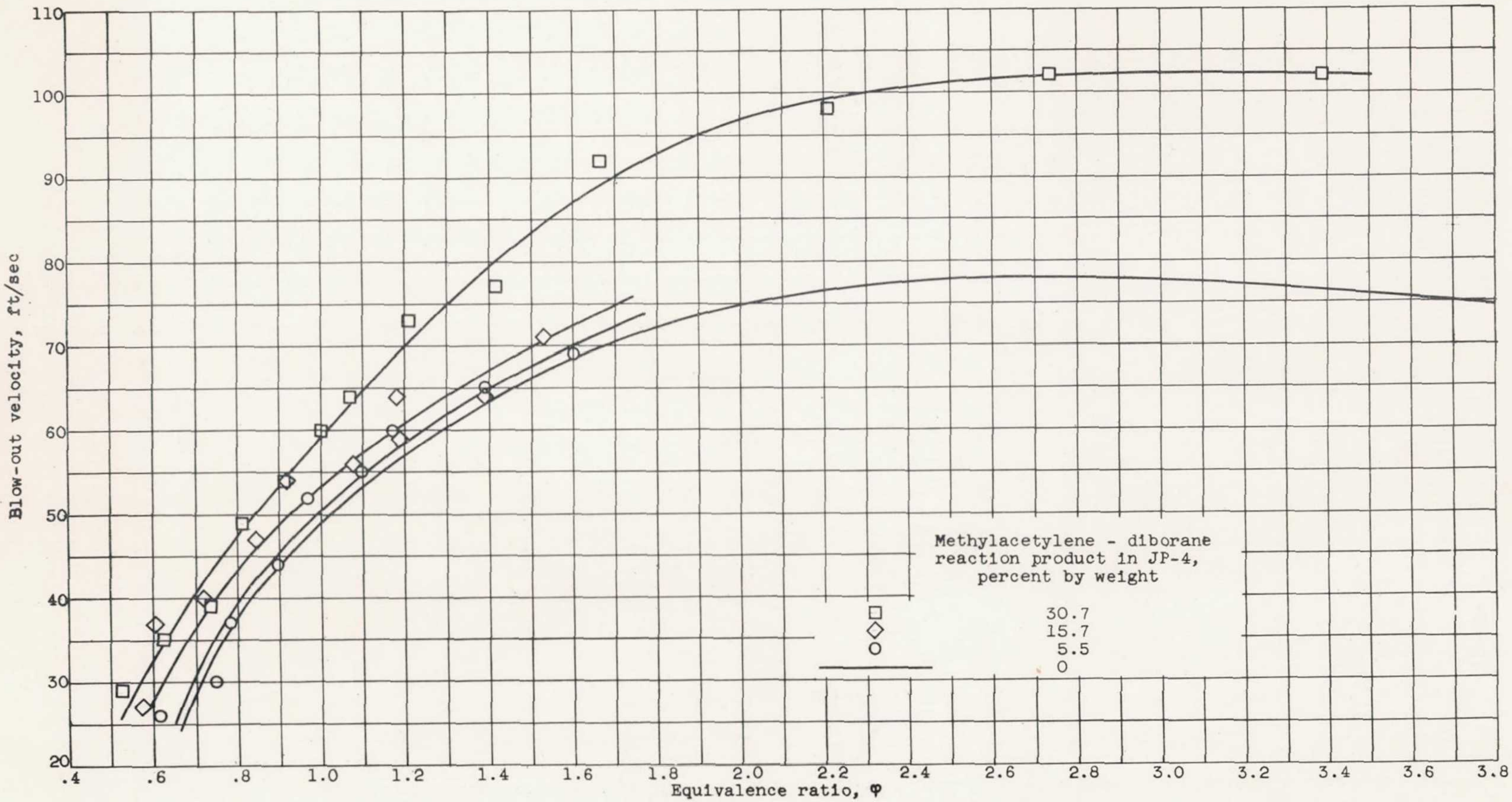

Figure 4. - Blow-out velocities of solutions of a methylacetylene - diborane reaction product in JP-4 solutions.

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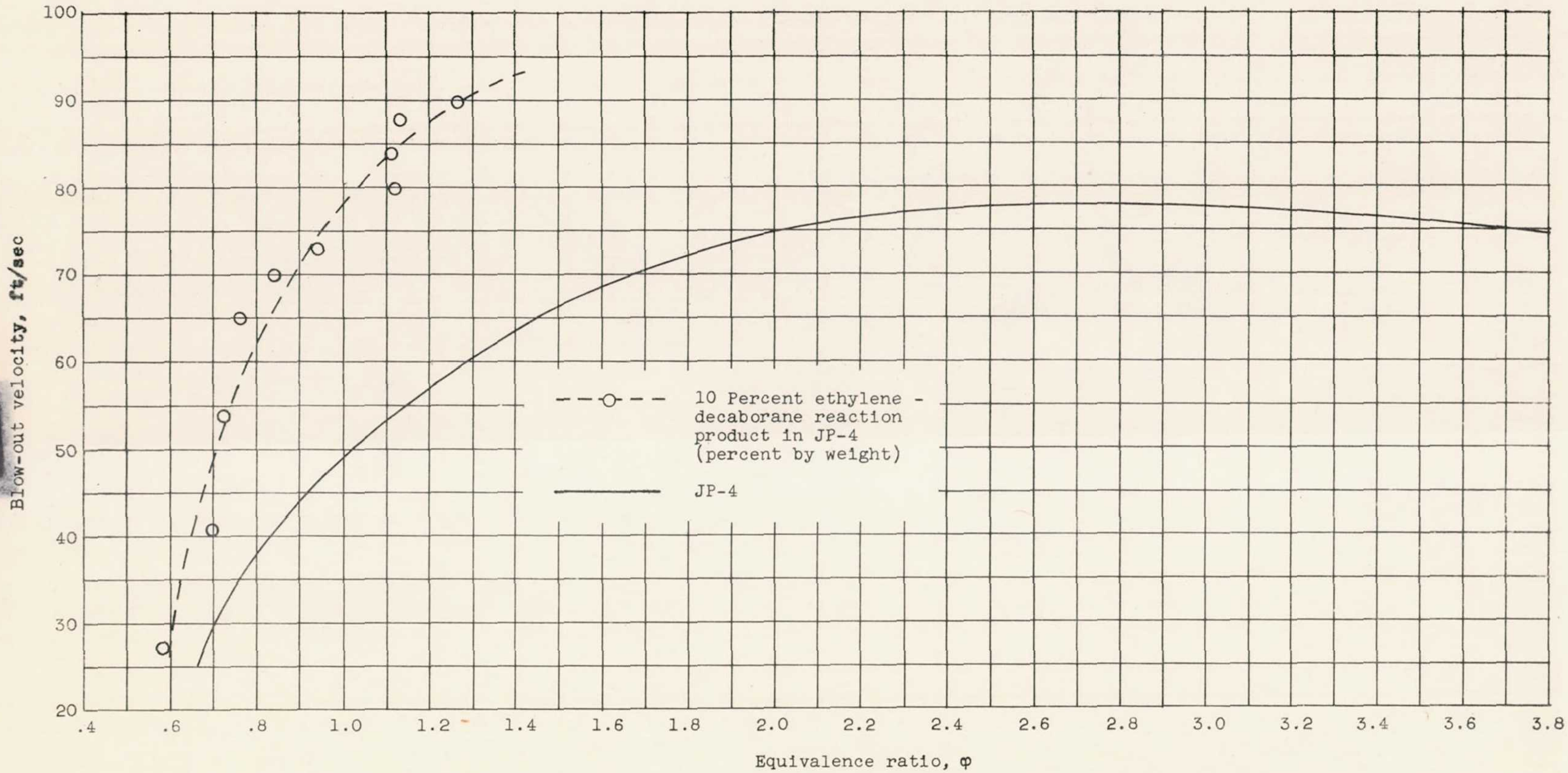

Figure 5. - Blow-out velocities of 10-percent ethylene - decaborane reaction product in JP-4 solution.

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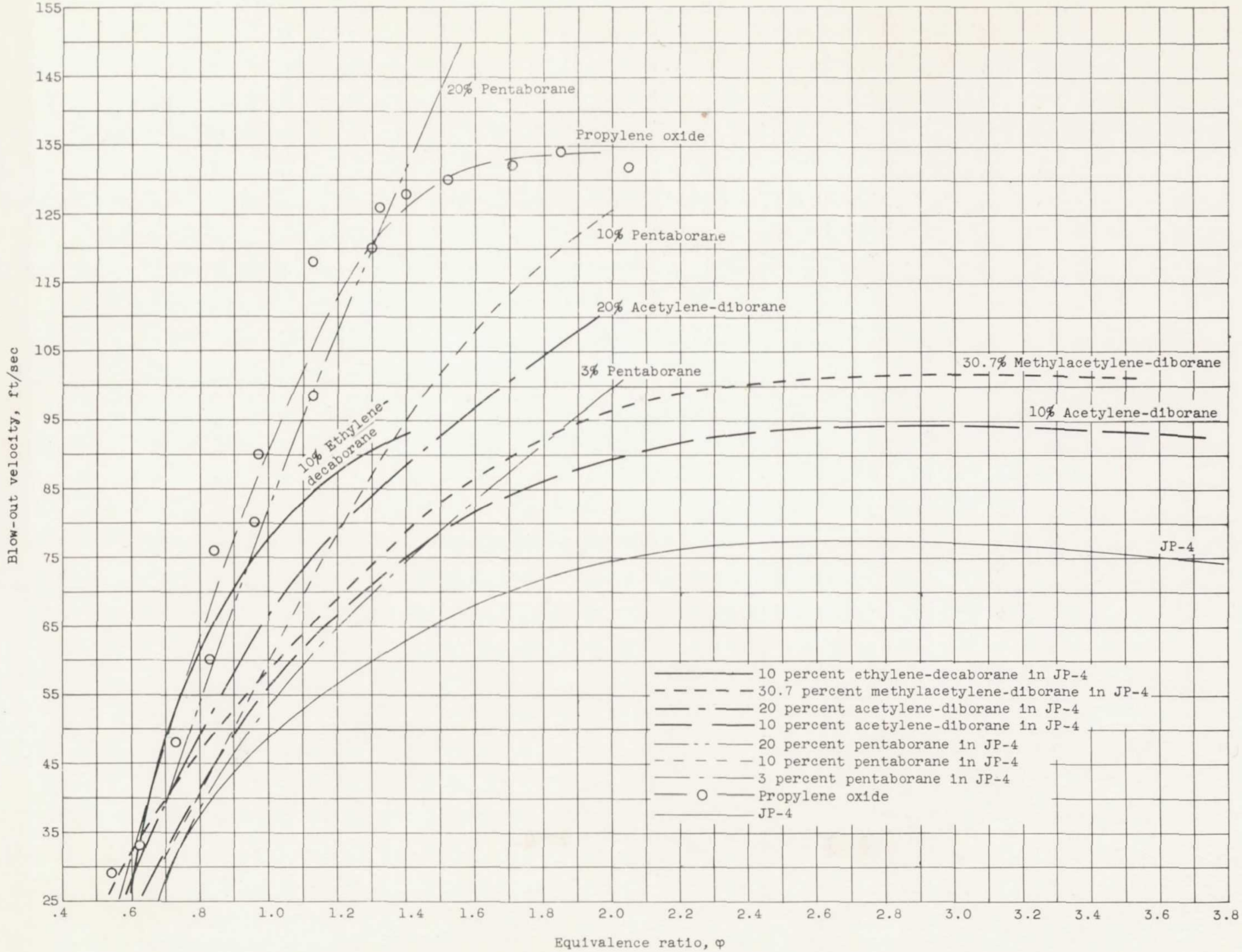

Figure 6. - Blow-out velocities of boron hydride - hydrocarbon reaction products solutions, JP-4, and propylene oxide.

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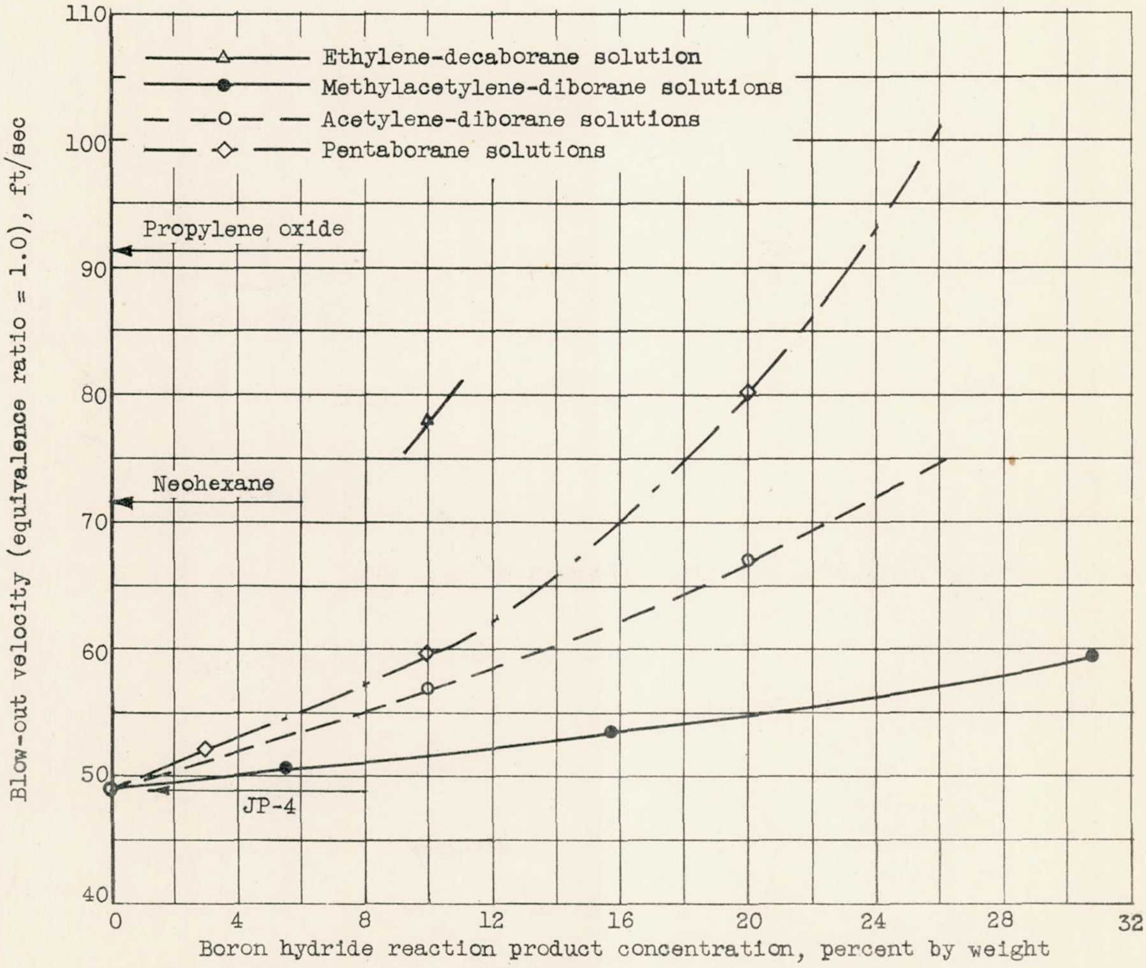

Figure 7. - Blow-out velocities at equivalence ratio of 1 for boron hydride - hydrocarbon reaction product solutions in JP-4.

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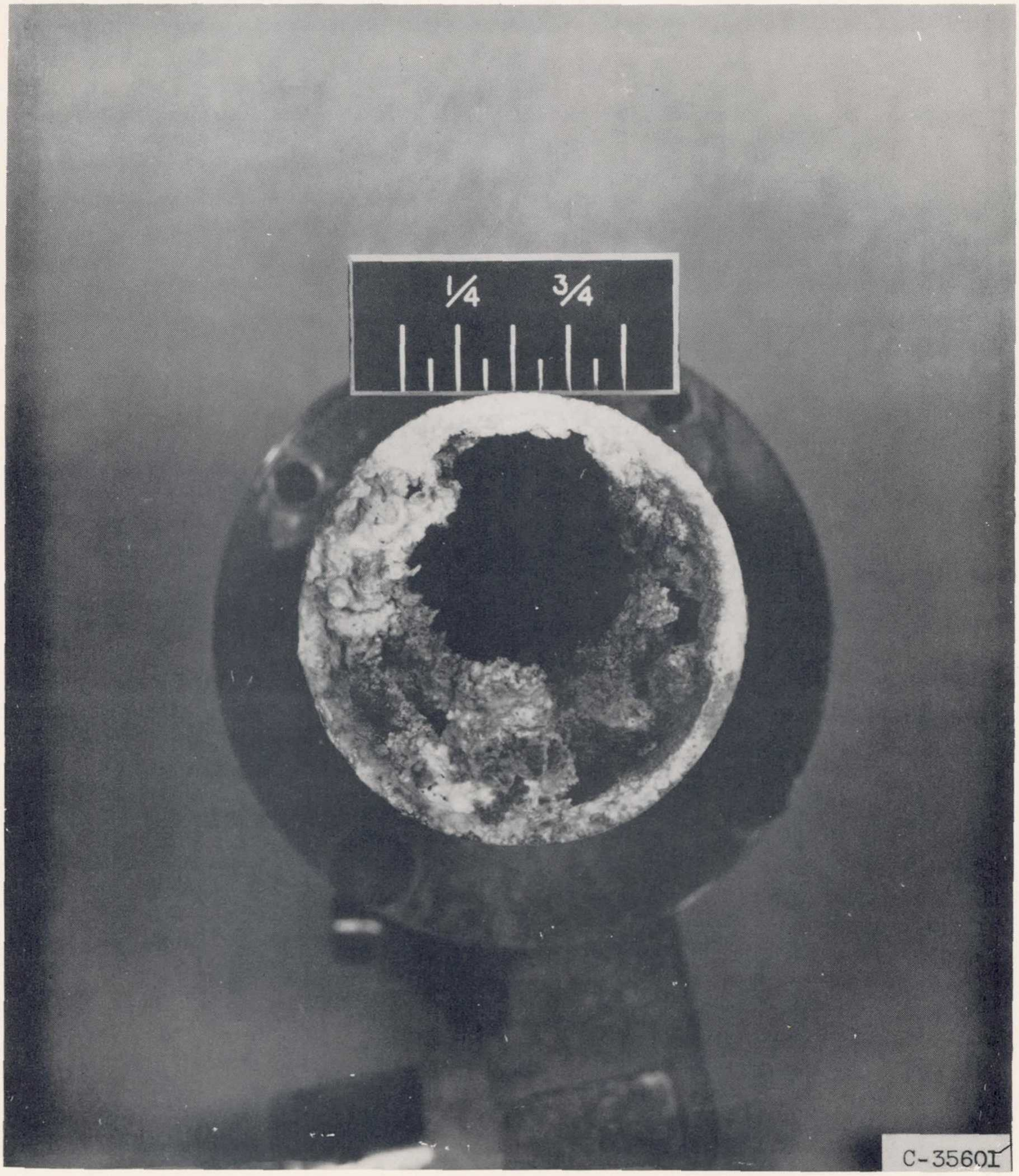

Figure 8. - Front view of combustor after high-equivalence-ratio burning of 30.7 percent methylacetylene - diborane reaction product solution.

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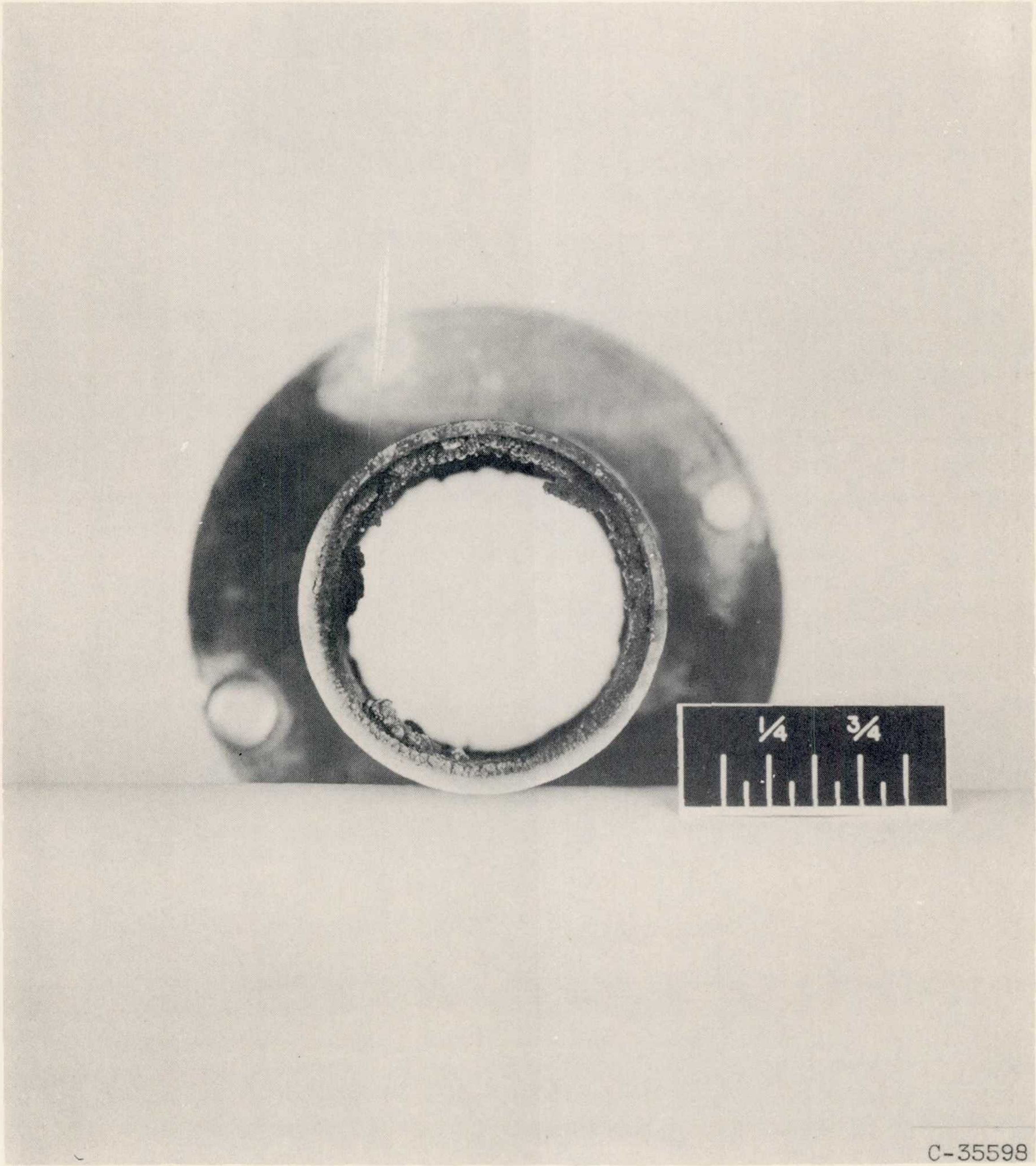

Figure 9. - Front view of combustor after high-equivalence-ratio burning of 20 percent acetylene - diborane reaction product solution.

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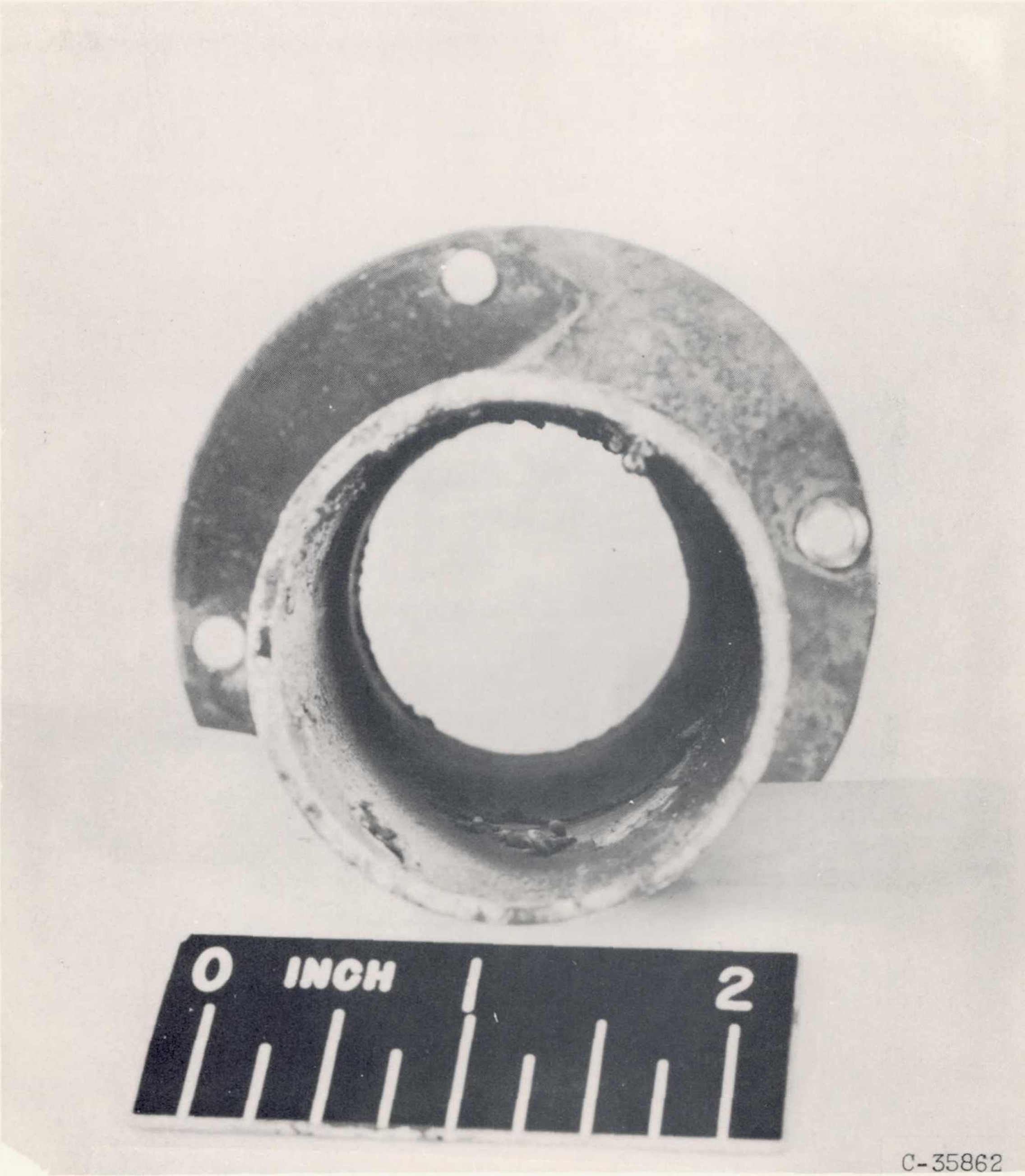

Figure 10. - Front view of combustor after high-equivalence-ratio burning of 10 percent ethylene - decaborane reaction product solution.

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BLOW-OUT VELOCITIES OF SOLUTIONS OF HYDROCARBONS AND BORON HYDRIDE - HYDROCARBON REACTION PRODUCTS IN A $1\frac{7}{8}$-INCH-DIAMETER COMBUSTOR

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Fuels - Properties, Physical and Chemical 3.4.2

Fuels - Turbine Engines, Ram Jets, and Pulse Jets 3.4.3.2

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Abstract

Blow-out velocities were determined for JP-4 solutions containing: (1) 10% ethylene - decaborane reaction product, (2) 10% and 20% acetylene - diborane reaction product, and (3) 5.5%, 15.7%, and 30.7% methylacetylene - diborane reaction product. These were compared with blow-out velocities for JP-4, propylene oxide, and neohexane and previously reported data for JP-4 solutions of pentaborane. For those reaction products investigated, the blow-out velocities at a fixed equivalence ratio were higher for those materials containing higher boron concentrations; that is, blow-out velocity increased in the following order: (1) methylacetylene - diborane, (2) acetylene - diborane, and (3) ethylene - decaborane reaction products.

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